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Bulldozer Fireline Production Rates—1988 Update

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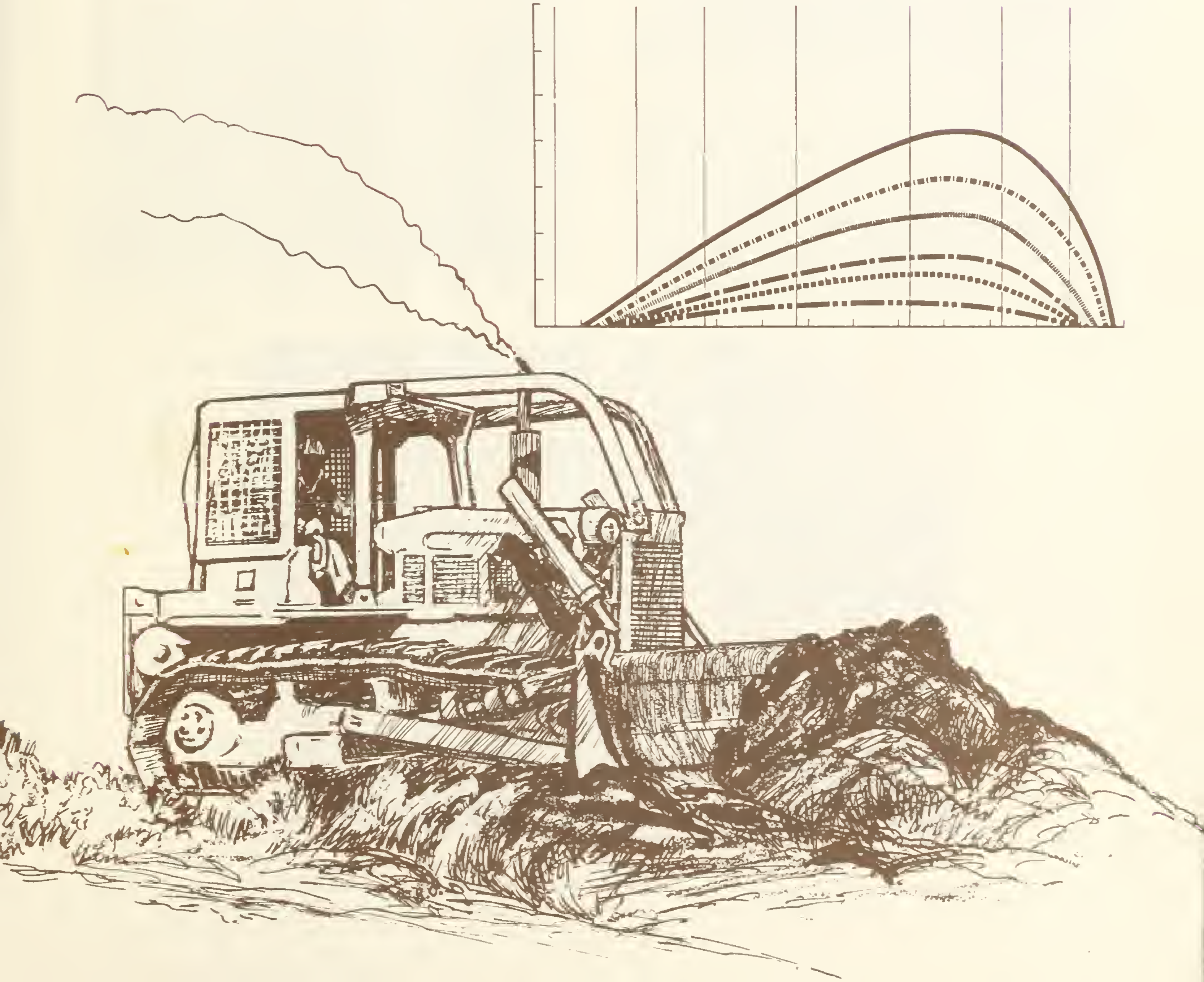

THE AUTHORS

CLINTON B. PHILLIPS received a B.S. degree in forestry from the University of California, Berkeley, in 1947, at which time he was employed by the California Department of Forestry. During his 35 years with that department, he was a ranger unit manager, was assigned for 2 years to the Pacific Southwest Forest and Range Experiment Station in Berkeley to manage several fire research studies, was the department's fire research coordinator for 12 years, and was Assistant Chief of Fire Protection for the department for the last 10 years of his career. He is currently a consultant in rural and wildland fire protection and fire management planning.

CHARLES W. GEORGE received his B.S. degree in forest engineering in 1964 and M.S. degree in forestry in 1969. He joined Intermountain Station's staff in 1965 where he has conducted studies related to prescribed fire, pyrolysis and combustion, fire retardants, and aerial delivery systems. Presently Mr. George is Project Leader of the Fire Suppression Research Work Unit at the Intermountain Fire Sciences Laboratory, Missoula, MT. The current mission of the work unit is to develop the knowledge and systems that will improve fire control capabilities and facilitate fire management planning, with emphasis on improving chemical fire suppression technology.

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RESEARCH SUMMARY

Bulldozers are an effective but expensive machine for building fireline; therefore, it is important for fire managers to have some means of estimating the rate at which various sizes of bulldozers can build fireline in different fire behavior fuel models and slope classes. Handbooks and reports currently available show bulldozer production rates that are revisions of studies made in the late 1950's and late 1960's. Not only are the production rates in those handbooks and reports outdated, they also present illogical combinations of fire behavior fuel models, and they do not differentiate major differences in production rates for upslope and downslope operation.

The goal of this study was to develop production rates for bulldozers manufactured since 1965, and especially for those manufactured since 1975. Tentative rates that were derived mathematically were published in 1984. Verification of those rates was tested in the field, measuring the production rates for bulldozers as they constructed firelines around prescribed fires. This report presents a revised table of production rates based on the results of the field tests. The table gives a range of production rates for three size-classes of bulldozers, a more logical set of combinations of the 13 fire behavior fuel models and four slope classes (both upslope and downslope), and specifies rules for selecting proper rates from the tables for different sets of field conditions.

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INTRODUCTION

In recent years, the use of bulldozers to construct firelines around wildland fires or prescribed fires has been curtailed in some fragile ecosystems. The heavy machines are still valuable in many situations, however, especially for moving large volumes of vegetation in a comparatively short time while constructing a fireline to mineral soil (fig. 1). For planning purposes wildland fire managers need to know the rates at which bulldozers can be expected to construct firelines in different combinations of vegetation, slope, and soil. Unfortunately, recent fireline handbooks and other publications (British Columbia Forest Service 1976; National Wildfire Coordinating Group 1980; Schmidt and Rinehart 1982; USDA Forest Service 1980) have presented production rates based upon studies made some 20 to 40 years ago (California Division of Forestry 1967; USDA Forest Service 1948). The rates in those publications do not apply to more modern bulldozers, are presented in a form that ignores important differences in rates of constructing firelines upslope and downslope, and in some cases are confusing in their relation to various fuel models.

In 1982-83 an effort was made to update older rates of fireline construction for bulldozers. Tentatively updated rates were published in the report by Phillips and Barney (1984). Those rates, shown in tables 1 and 2, were derived mathematically in the following manner:

1. Rates obtained in earlier field studies were selected as "base rates" (California Division of Forestry 1967; Steele 1961).
2. The base rates were adjusted to fit newer models of bulldozers by using production indexes established by the manufacturers of bulldozers for earth-moving applications.
3. The adjusted rates were related to four variables:
    a. Each of the 13 fire behavior fuel models (Anderson 1982).
    b. Both upslope and downslope construction of firelines.
    c. The first three slope classes of the National Fire-Danger Rating System (Deeming and others 1977).
    d. Three size classes of bulldozers arbitrarily established by using the following criteria:

Figure 1—Bulldozer constructing fireline through light fuel around an area scheduled for prescribed burning.

Criteria	Size class Small	 Medium	 Large
Weight (tons)	5-10	11-20	21-40
Net horsepower	55-95	100-195	200-350
Blade width (ft)	8-9	10-12	13-16
Track gauge (ft)	5+	6+	7+
Track area on ground (in²)	1,500-2,900	3,000-4,200	4,300-6,300
NIIMS type	3	2	1

Many other conditions were held constant and were consistent with the studies of Steele and the Studies of the California Division of Forestry: single-pass fireline, indirect line location, only the best qualified operators, equipment in good operating condition, no lost time, average fire behavior, dry soil with reasonably good traction and no rock obstacles, air temperature ranging from 85 to 105 °F (29 to 41 °C), and line construction during daylight hours only. The rates were published in two tables (republished as tables 1 and 2 in this report). It was noted that if actual conditions varied from the assumed conditions, then the production rates would have to be adjusted accordingly. The magnitude of adjustment was not indicated. Field verification of the tentative rates started in the summer of 1983 and continued through 1986. This report reflects the results of those field studies and presents revisions to the tables published in 1984.

PLANNING AND CONDUCTING THE VERIFICATION STUDY

As part of the initial study, a procedure was developed for testing bulldozer fireline production rates (Phillips 1983). Based upon techniques used in the earlier studies of bulldozers (California Division of Forestry 1967; Steele 1961), the procedure would require a minimum of 3 days of field tests, at least three bulldozers (one each small, medium, and large size), 18 people, a considerable array of supporting equipment, fuel and servicing for bulldozers and other vehicles, and expenses for travel, housing, meals, and general logistical support. Also the tests would require an extensive area of land, including several fuel models, which would be disturbed considerably by the bulldozers building fireline to mineral soil. For comparison, during 5 weeks in the summer of 1967, the California Department of Forestry tested four small and three medium bulldozers which involved 45 people in an area of several hundred acres. The decision was made in 1983 that such a field study was desirable but beyond the fiscal ability of the USDA Forest Service to perform at that time.

Another alternative was selected. The field verification of bulldozer fireline production rates would be made by following bulldozers as they constructed lines around

Table 1—Bulldozer fireline production rates (single pass) for bulldozers manufactured since 1975

Fire behavior fuel model	Slope class 1 (0-25%) Up	 Down	Slope class 2 (26-40%) Up	 Down	Slope class 3 (41-55%) Up	 Down
	Chains per hour					
Small bulldozers						
1, 2, 3	63	88	36	88	14	61
4	22	29	12	30	3	22
5	63	88	36	88	14	61
6	39	59	22	62	8	42
7	39	52	22	56	8	35
8	63	88	36	88	14	61
9,11,12	22	30	12	30	3	11
Medium bulldozers						
1, 2, 3	88	118	58	112	35	73
4	32	47	18	53	5	31
5	88	118	58	112	35	73
6	51	75	26	78	9	48
7	51	75	27	78	9	48
8	88	118	58	112	35	73
9, 11, 12	32	47	18	53	5	31
10,13	17	23	10	25	3	11
Large bulldozers						
1, 2, 3	91	124	62	118	35	83
4	43	60	27	62	12	40
5	91	124	62	118	35	83
6, 7	63	91	41	90	22	57
8	91	124	62	118	35	83
9, 11,12	43	60	27	62	12	40
10, 13	27	38	15	34	4	16

Table 2—Bulldozer fireline production rates (single pass) for bulldozers manufactured since 1965-75

Fire behavior fuel model	Slope class 1 (0-25%) Up	 Down	Slope class 2 (26-40%) Up	 Down	Slope class 3 (41-55%) Up	 Down
	Chains per hour					
Small bulldozers						
1, 2, 3	63	88	36	88	14	61
4	22	29	12	30	3	22
5	63	88	36	88	14	61
6	41	57	22	58	8	37
7	41	57	22	58	8	37
8	63	88	36	88	14	61
9, 11, 12	22	30	12	29	3	13
Medium bulldozers						
1, 2, 3	85	112	57	107	34	71
4	30	44	16	50	4	30
5	85	112	57	107	34	70
6	49	72	26	75	7	47
7	49	72	26	75	7	47
8	85	112	57	107	34	71
9, 11, 12	30	44	16	50	4	30
10, 13	17	25	11	24	3	9
Large bulldozers						
1, 2, 3	82	111	55	105	32	74
4	38	54	24	55	11	36
5	82	111	55	105	32	74
6, 7	57	82	37	80	20	51
8	82	111	55	105	32	74
9, 11, 12	38	54	24	55	11	36
10,13	24	34	13	30	4	14

planned prescribed fires and going wildfires. This alternative, while within the study's fiscal constraints, had some serious shortcomings as it turned out.

Early in the verification study it became evident that following bulldozers around going wildfires was not too practical. First, during the years of the study, few wildfires occurred that were reachable by the study's observer before the fires were contained. On two fires that the observer was able to reach quickly, bulldozers were used only to place protective lines around residences. Several times the observer was traveling and was not available when potential situations for study arose; that was the case especially in the summer of 1985 when so many large wildland fires occurred in California. For those and other reasons, the verification study was confined to recording bulldozer production rates during the construction of firelines around planned prescribed fires in northern California.

The study's observer established a network of people who were involved in fuel management programs throughout northern California. Regular contacts were made with 15 Ranger Districts in seven National Forests of the Forest Service and nine Ranger Units in three Regions of the California Department of Forestry. Each spring, telephone calls were made to learn which administrative units would probably use bulldozers to construct lines around planned prescribed fires. Followup calls were then made throughout the spring, summer, and fall months, as needed, to determine exact days, times, and locations of work to be done.

From these contacts one fact soon became clear: both the Forest Service and the California Department of Forestry no longer use bulldozers to construct firelines around prescribed fires to the extent that they did just a few years ago. Two primary reasons emerged: (1) at a time of reduced budgets bulldozers are increasingly expensive to operate, and (2) bulldozers often disturb the soil to an unacceptable degree. Because bulldozers are an expensive tool, the Forest Service has reduced in recent years the number of machines it owns and depends more on contractual equipment. In the case of the California Department of Forestry, that agency allows private landowners to use their own bulldozers to construct lines around prescribed fires as the landowner's major contribution to the overall cost of a cooperative fuel management project. As the study soon revealed, private bulldozers are sometimes old, poorly maintained, and operated with a relatively low level of skill. Production rates obtained from most of them are therefore not too comparable to the rates in the published tables.

As another means of reducing use of their own bulldozers, both the Forest Service and the California Department of Forestry rely more on established roads or natural breaks in laying out the perimeters of prescribed fires. That technique may produce a prescribed fire that is larger or a different shape than originally planned, but it meets the agencies' objectives of reducing the costs of prescribed fires and of reducing soil disturbance. The result, in terms of the verification study, was fewer opportunities to study bulldozer production rates than might have been expected in the recent past.

Another objective of the verification study was to make at least some tests at night. Such tests were attempted on two occasions, but it was found that required observations simply could not be made well at night. The primary problem was the refraction of the bulldozer's lights and the observer's flashlight through the thick cloud of dust. It was difficult or impossible to see well enough to anticipate when the slope was changing 5 percent or more, to identify landmarks for measuring points of slope changes and distances, and to read the Abney level. Consequently, only one set of data and some general observations were obtained for night operations.

The study's observer sought and managed to find a range of operating conditions. Bulldozers varied widely in terms of manufacturer, age, and operating condition. There was a wide range in the experience and skill of the operators, perhaps the single most important factor influencing bulldozer production rates. Soil conditions were also very important in influencing production rates. At two locations, granite boulders were so large and numerous that constructing any sort of a control line was an accomplishment; production rates were, not unexpectedly, exceedingly slow. At the other extreme, certain firelines were constructed with ease. During the spring of 1986, at a site where the soil was still damp from an abnormally wet winter, bulldozers obtained excellent traction and had little difficulty in uprooting heavy chaparral from the moist soil. Observed production rates were much greater than those found in tables 1 and 2. Air temperature throughout the verification tests was never a limiting factor in the operation of the bulldozers, generally ranging between 80 to 96 °F. Air temperature above 100 °F causes some bulldozers to overheat and produce slower rates of line construction.

Table 3 shows the form designed for recording and calculating data, along with typical data and remarks.

Information about the bulldozer was desirable to establish the machine's age, operating characteristics, and which curve of production rates (Phillips and Barney 1984) should be used. Although it was impossible to measure each machine's mechanical condition, it was assumed that both the USDA Forest Service and the California Department of Forestry provided a high level of maintenance. Conversations with both agencies' employees and inspection of maintenance books for a few machines generally confirmed that fact. Perhaps the best subjective measure of operator skill was years of experience, as observed during the four summers of the study.

A "line" was arbitrarily defined as a major segment of a prescribed fire's perimeter, generally from one road or anchor point to another. A "run" within a line was defined as being wholly (or nearly so) within one fuel model and within a 5 percent slope. Whenever either of those two criteria changed, a new run was recorded (table 3). Most often the study's observer did all the measuring and recording while following a bulldozer. Agency representatives occasionally assisted the observer, especially in measuring distances, as their time permitted.

Data for columns 1, 2, 3, 4, 6, and 9 of the tally sheet were recorded in the field. Numbers for columns 5, 7, 10, 11, 12, and 13 were calculated later. The fire behavior fuel model was selected in agreement with the agency's

Table 3—Tally sheet for recording bulldozer fireline production rates in verification study[1]

Bulldozer size (circle one): S M L

Make, Model, Year ______________________

Serial No. ______________________

Hour reading, start: ______________________

finish: ______________________

Operator's name ______________________

Years of experience ______________________

Line No. ______________________

General location ______________________

____

____

Date ______________________

Observers ______________________

____

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
				NFDRS	Time of run					Production rate		
	Fire behavior			slope		Mins	Hour	Distance		(chains/hour)		
Run	fuel model	Slope		class	Min:Sec	(0.01)	(nearest 0.001)	Slope	Horizontal	Test	Table	±Δ%
		Percent	*Degree*					*Ft*	*Chains*			
1	3	–5	–3	–1	1:40	1.67	0.028	200	3.03	108	118	–8
2	4	–30	–17	–2	4:03	4.05	.068	197	2.85	42	53	–21
3	4	–15	–9	–1	3:30	3.50	.058	153	2.29	39	47	–17
4	4	–51	–27	–3	5:00	5.00	.083	305	4.12	50	31	+61
5	1	+22	+12	+1	3:44	3.73	.062	351	5.20	84	75	+12
6	1	–5	–3	–1	7:48	7.80	.130	1119	16.93	130	108	+20

Air temperature about 92 °F. Run No. 1 in annual oats about 3-4 feet high. Runs Nos. 2-4 in mature chaparral up to 30 ft high consisting of manzanita, ceanothus, live oak, coffeeberry, toyon, and poison oak. Runs Nos. 2 and 3 had a few outcrops of "tombstone shale" angled upward toward dozer's blade. Runs Nos. 5 and 6 in shorter grass in poor soil.

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[1] Cols. 1, 2, 3, 4, 6, 9 = field observations;
Cols. 5, 7, 8, 10, 11, 12, 13 completed in office;
Col. 10: Horizontal dist. (chains) = slope dist. (ft) x cos slope (°) ÷ 66.

representative, using the publication by Anderson (1982). Slope was observed with an Abney level (usually aiming at an established point on the rear of the bulldozer) and recorded in both percentage (for use with the production curves and to establish the slope class of the National Fire-Danger Rating System) and degrees (for calculating the horizontal distance in column 10 of the tally sheet). Time was observed with a stop watch in minutes and seconds (column 6) and then converted to hours (column 8) for use in calculating the production rate (column 11). Slope distance was measured with a 100-foot tape on steep and rocky slopes, with frequently tested pacing on less demanding slopes. To obtain horizontal distance in chains, the slope distance in feet was multiplied by the cosine of the slope angle in degrees and divided by 66 (a handheld scientific calculator was helpful!). The production rates in column 11 were calculated by dividing the horizontal distance (column 10) by time (column 8). The calculated rates were then compared to the adjusted rates (column 12) taken from the appropriate curve (Phillips and Barney 1984).

The adjusted rates were taken from the curves in figures 12-17 of the 1984 publication and not from tables 4 and 5 of that publication. That procedure was used so that the rates would be more closely related to the actual slope recorded in column 3 of the tally sheet. The rates recorded in tables 1 and 2 were only for the midpoints of the broad slope classes and therefore would not be as accurate as rates taken from the appropriate points on the curves. The percentage difference between the adjusted rates (from the 1984 publication) and the observed rates (from the verification study) was recorded in column 13 of the tally sheet.

The limited opportunities to conduct verification studies in the field produced the number of tests shown in table 4. The runs and distances shown in table 4 were distributed by bulldozer size, fire behavior fuel model, and slope class as shown in table 5. As table 5 shows, few combinations of fuel models and slope classes were tested enough to permit a satisfactory verification of the adjusted rates in tables 1 and 2. Nevertheless, some broad interpretations of the data can be made.

Table 4—Tests made in 1983-86 to verify bulldozer fireline production rates

Year	Number locations	Number lines	Number runs	Horizontal distance
				Chains
1983	2	3	16	49.39
1984	3	5	38	223.40
1985	8	17	51	442.91
1986	3	16	91	736.39
Total	16	41	196	1,452.09

Table 5—The number of runs of three sizes of bulldozers observed during the verification study, distributed according to fire behavior fuel model and slope class

Fire behavior fuel model	Bulldozer size	Slope class 1 (0-25%)		Slope class 2 (26-40%)		Slope class 3 (41-55%)		Total runs	Total horizontal distance
		Up	Down	Up	Down	Up	Down		
									Chains
1	Medium	25	17	2	1			45	306.68
2	Small	3	2					5	19.20
	Medium	2	1					3	20.98
	Large	9	1					10	340.04
3	Medium	1	2		2	2	1	8	30.91
4	Small	4	3	13	16	3	3	42	206.44
	Medium	5	5	7	11	2	6	36	161.60
	Large		2		3			5	10.52
5	Medium	3	2		1			6	41.20
6	Medium	4	6		1			11	100.61
	Large	1						1	3.33
7	None								
8	None								
9	Medium	9	1					10	155.76
10	None								
11	Small		2		2			4	15.92
	Large	4	3	1	1			9	36.16
12	Large		1					1	2.74
13	None								
Total		70	48	23	38	7	10	196	1,452.09

RESULTS OF THE VERIFICATION STUDY

The primary objective of the verification study was to determine how well the observed bulldozer production rates calculated in column 11 of the tally sheet (table 3) compared with the adjusted rates in tables 1 and 2. This comparison is shown in table 6. In each cell of the table the average percentage difference of the observed rate is shown as being greater (+) or less (–) than the adjusted rate and is followed, in parentheses, by the number of runs from which the average percentage difference was derived. The average percentage difference was calculated from the percentage difference for each run, weighted by the length of the run in chains. Assuming that at least 10 runs were needed to provide a statistically valid average, then few cells in table 6 met that criterion. Even where the number of runs appeared adequate for statistical analysis, in many instances the data were conditional and needed careful interpretation for the various fire behavior fuel models (FBFM), as follows:

Fire Behavior Fuel Model 1—As table 6 shows, data for this fuel model were obtained only with medium bulldozers and almost entirely in slope class 1. Assuming the data in slope class 1 were accurate, however, the adjusted rates in tables 1 and 2 should be increased.

Fire Behavior Fuel Model 2—There were few data for this fuel model. Nevertheless, the direction of change seemed to be the same as for Fire Behavior Fuel Model (FBFM) 1. As observed in the field studies, there was little if any difference between FBFM's 1 and 2 in respect to their resistance to line construction by bulldozers.

Table 6—The average percent difference between bulldozer fireline production rates observed during the verification study and the adjusted rates from tables 1 and 2[1]

Fire behavior fuel model	Bulldozer size	Slope class 1 (0-25%)		Slope class 2 (26-40%)		Slope class 3 (41-55%)	
		Up	Down	Up	Down	Up	Down
1	Medium	+18%(25)	+3%(17)	+26%(2)	+30%(1)		
2	Small	+53%(3)	+24%(2)				
	Medium	+20%(2)	–41%(1)				
	Large	+154%(9)	+111%(1)				
3	Medium	–24%(1)	–15%(2)		–5%(2)	+10%(2)	–44%(1)
4[2]	Small	+97%(4)	+104%(3)	+113%(13)	+124%(16)	+251%(3)	+127%(3)
	Medium	+45%(5)	+63%(5)	+109%(7)	+52%(11)	+313%(2)	+102%(6)
	Large		–31%(2)		–66%(3)		
4[3]	Medium	+45%(5)	+62%(5)	+45%(4)	–5%(7)		+51%(2)
5	Medium	+20%(3)	–50%(2)		–30%(1)		
6[4]	Medium	–9%(4)	–9%(6)		–49%(1)		
	Large	+51%(1)					
6[5]	Medium	+36%(1)	+7%(3)		–49%(1)		
	Large	+51%(1)					
7	None						
8	None						
9	Medium	+107%(9)	+91%(1)				
10	None						
11	Small		–40%(2)		–24%(2)		
	Large	+3%(4)	–20%(3)	+23%(1)	–19%(1)		
12	Large		–31%(1)				
13	None						

[1] Percentages in the table are the percent differences in bulldozer fireline production rates followed, in parentheses, by the number of runs observed to obtain those differences.

[2] Includes observations made at a site where soil was moist, providing bulldozers with excellent traction and easing the uprooting and moving of heavy chaparral.

[3] Includes observations made only at sites where the soil was summer-dry.

[4] Includes observations made at two sites where there was a continuous expanse of large granitic boulders, atypical of most wildland fires in this fuel model.

[5] Includes observations made at sites where the soil contained amounts and sizes of rocks more typical of where wildland fires occur in California.

Therefore, the authors continued to combine those two fuel models for the purpose of publishing bulldozer fireline production rates.

Fire Behavior Fuel Model 3—Few data were obtained for this fuel model. The sparse number of observations indicated, however, that FBFM 3 should be separated from FBFM's 1 and 2 (they are together in tables 1 and 2) and given a slower production rate.

Fire Behavior Fuel Model 4—Unfortunately, most of the data obtained for this fuel model (shown in table 6 on the line for FBFM 4[2]) came from one site where the soil was still damp from the above-normal precipitation of the previous winter and spring. The moist soil provided excellent traction for the small and medium bulldozers that were observed and also allowed the machines to easily uproot or cut the stems of the tall (12 to 20 feet), mature chaparral. Because of the moist soil and the cool air temperature (80 °F), the observed production rates at that site were phenomenally good, even at slopes of 55 percent for the medium bulldozers. If nothing else, the observations at that site confirmed the much higher production rates to be expected from bulldozers when operating in moist soils with few inhibiting rocks. Although the authors preferred not to include those data in their consideration of changes to be made to the rates in tables 1 and 2, it was clear from observations at other sites (shown in table 6 on the line for FBFM 4[3]) that the rates for FBFM 4 needed to be increased.

Fire Behavior Fuel Model 5—A shortage of data for this fuel model did not provide a basis for changing the adjusted rates in tables 1 and 2. If any adjustments were to be made, the few data indicate that adjusted rates should be increased slightly for upslope production in slope class 1, and that downslope rates should be decreased for slope classes 1 and 2.

Fire Behavior Fuel Model 6—Large granite boulders presented formidable obstacles at two of the four sites where bulldozers were observed in this fuel model. The boulders caused production rates that were consistently 40 to 50 percent below the adjusted rates in tables 1 and 2. If nothing else, the observations at those two rocky sites gave good measures of the differences in production rates to be expected between very rocky terrain and the assumed condition of more favorable soil. Using only the few data obtained at the two sites where some rocks were present but not limiting, the observations indicated that the production rates for FBFM 6 should be increased for slope class 1 and possibly decreased for downslope operations in slope class 2. Those conclusions were not really valid, however, in light of the paucity of data.

Fire Behavior Fuel Model 7—This fuel model (southern rough) does not occur in California, and the normal tactical tool used to construct fireline is the tractor/plow. For the purpose of providing bulldozer production rates, however, the authors assume that the spacing of pine and other trees would not unduly restrict the passage of bulldozers. The resistance to fireline construction by bulldozers in this fuel model, therefore, would seem to be about the same as that in FBFM 6 (medium brush). With that reasoning, the authors combined FBFM's 6 and 7 in the display of fireline construction rates.

Fire Behavior Fuel Model 8—No data were gathered for this fuel model. Vegetational conditions for this model seem to offer only moderate resistance to bulldozer operation. As with FBFM 7, the authors assume that the spacing of trees in FBFM 8 would not unduly restrict the passage of bulldozers. The only obstacles would be occasional "jackpots" of accumulated dead fuel or small trees that might have to be pushed over. Based upon this assumption, bulldozer production rates in this fuel model could be combined with those in FBFM's 3 and 5.

Fire Behavior Fuel Model 9—The few data for this fuel model indicated that the adjusted rates in tables 1 and 2 were too low. At the three sites where observations were made in this fuel model, it was seen that medium-sized bulldozers, at least, could easily maneuver among the larger trees. Only occasionally was the construction of fireline slowed by the need to push over a sapling or two or to remove a fallen tree. For the most part, line construction was through the litter of leaves, needles, and fallen branches. Production rates, therefore, were consistently much faster than those shown in tables 1 and 2. Whether this increase in production rates would be true with large bulldozers is open to interpretation based upon spacing of large trees in this fuel model. If large bulldozers had been used at the same three sites as in this study, they should have been able to construct fireline at the same faster rates as observed for the medium bulldozers, in the observer's judgment.

Fire Behavior Fuel Model 10—No data were obtained for this fuel model. Therefore no changes should be made to the adjusted rates shown in tables 1 and 2.

Fire Behavior Fuel Model 11—Few data were obtained for this fuel model. The limited number of data indicated that large bulldozers might produce fireline at somewhat greater rates upslope for slope classes 1 and 2 than shown in tables 1 and 2, but at somewhat decreased rates downslope. The few data for small bulldozers also indicated slower production rates for downslope lines than those shown in tables 1 and 2.

Fire Behavior Fuel Model 12—The single observation made in a medium volume of slash did not permit any change to the production rates in tables 1 and 2 at this time.

Fire Behavior Fuel Model 13—No data were obtained for this heavy slash model. Therefore, no changes should be made at this time to the adjusted rates shown in tables 1 and 2.

One objective of the verification study was to confirm the absence of production rates for slope class 4 in tables 1 and 2. This slope class was omitted because the class' midpoint of 65.5 percent was at or above the maximum gradability for most bulldozers. The CDF's tests in 1967 showed that maximum gradability in light grass and favorable soil type averaged 75 percent for medium bulldozers with raised blades in forward gear; maximum gradability was about 65 percent in reverse gear. For small bulldozers the corresponding numbers averaged 67 percent in forward gear and 56 percent in reverse gear. Further, the 1967 study showed that line could be constructed up to a maximum gradability only if vegetation was light (low resistance to line construction) and soil conditions provided good traction. The 1967 study also showed that, while there was a gradual reduction in line production for steepening grades upslope, there was a gradual increase in line production for steepening grades downslope to the point where steepness caused bulldozer operators to have difficulty in backing up for the purpose of clearing their blades and taking another run at cleaning the line. Some bulldozer operators think that with angled blades they can work downslope without having to back up, thus they are not limited by maximum gradability in reverse gear. But if they hang up against a tree, stump, or rock, or suddenly lurch into a steep incline, or face a fire that has unexpectedly changed direction and is coming directly upslope toward them, they must be able to back up. Hence, maximum gradability in reverse gear is still an important limiting factor.

Maximum gradability was reviewed with equipment engineers and with instructors of bulldozer operation. They agreed unanimously that maximum gradability for newer machines has changed little since the CDF's tests in 1967. They found that operator's effectiveness and soil conditions were more important as limiting factors than recent improvements in bulldozer power, transmissions, tracks, and lubricating systems.

Nevertheless, there is room for effective line construction by bulldozers at least within the lower part of slope class 4. During the verification study one experienced operator was measured constructing line in FBFM 4 (tall, mature chaparral) at 55 percent grade, downslope, dry soil, at a rate of 44 chains per hour. That observation and several others around 50 percent slope, both upslope and downslope, confirmed that some production can be expected within slope class 4.

Given the few data from the verification study and the large number of important variables which affected those data, how could the fireline production rates for bulldozers be presented in a manner most useful to wildland fire managers, planners, and bulldozer operators? That question had to be answered before revising tables 1 and 2.

CRITERIA FOR DESIGNING TABLES OF BULLDOZER FIRELINE PRODUCTION RATES

Before designing a table of bulldozer fireline production rates the authors examined other published tables and also queried several wildland fire managers. From these examinations and discussions came the following criteria:

1. Differentiate the production rates by four variables:
    a. Three sizes of bulldozers.
    b. The 13 fire behavior fuel models.
    c. Slope classes of the National Fire-Danger Rating System.
    d. Direction of slope (upslope and downslope).
2. Keep the table simple, especially for fireline handbooks:
    a. Group the rates for as many fire behavior fuel models as practicable and reasonable.
    b. Round the rates off to the nearest 5 or 10 chains/hour.
    c. Have only one table of rates for all bulldozers of each size class; use a range of rates for each combination of the four variables listed above.

The authors found no difficulty in accepting the four variables to be used in the table. The three sizes of bulldozers, the 13 fire behavior fuel models, and the five slope classes of the National Fire-Danger Rating System are all well documented and accepted as standards by wildland fire managers.

But sometime in the past differentiation between upslope and downslope was dropped for bulldozer production rates. Why this happened has not been determined. As the rates in tables 1 and 2 show, there are substantial differences between upslope and downslope production within the same slope class. In slope class 1, production rates for downslope are as much as 50 percent greater than for upslope; in slope class 3, downslope rates are as much as 633 percent greater. Similar differences were shown in the Forest Service's Fireline Handbook (USDA Forest Service 1973) for Pacific Southwest Region as recently as June 1973. In at least three more recent publications, however, the upslope/downslope difference in production rates has been dropped and only a single rate given for each slope class (National Wildfire Coordinating Group 1980; Schmidt and Rinehart 1982; USDA Forest Service 1980). Because a single rate is not realistic, the authors have included both upslope and downslope rates in the final table in this report.

Side slopes may adversely affect line production by bulldozers, as reported by the CDF in 1967 (California Division of Forestry 1967). That agency's report said side slopes did not significantly affect upslope line production; downslope line production was reduced for side slopes of 30 percent or more, the amount of reduction depending on the balance of the individual bulldozer. During the verification study of 1983-86, no effort was made to measure the effect of side slope on production rates. In fact most line was constructed at right angles to the contours, and side-slope construction played a minor role.

Grouping bulldozer fireline production rates for two or more fire behavior fuel models seems feasible and, in fact, has been done in virtually every recently published table, including tables 1 and 2 of this report. After all, fire behavior fuel models were designed to reflect differences in expected fire behavior. They were not designed to give differences in the fuel models' resistance to line construction by bulldozers. For example, it is very evident that bulldozers should be expected to construct fireline at about the same rate in both fuel models 1 and 2, and the same thing should hold true for other combinations of fuel models. The tricky part comes in deciding what the combinations should be, especially in the absence of sufficient test data for production rates in some fuel models.

The recently published Federal tables (National Wildfire Coordinating Group 1980; Schmidt and Rinehart 1982; USDA Forest Service 1980) displayed some combinations of fuel models that are difficult to understand. Fuel model

2 (grass in open conifer), for example, was combined with fuel models 4 (mature chaparral), 9 (hardwood litter/ conifers West), 11 (light slash), and 12 (medium slash). At a much lower rate of production (apparently judged to be more resistant to line construction by bulldozers) was fuel model 3 (tall grass) combined with, among others, fuel models 5 (low brush—why more difficult than fuel model 4, tall chaparral?), and 13 (heavy slash). The most difficult vegetative types for bulldozer line construction were judged to be fuel models 8 (timber litter in closed hardwoods) and 9 (hardwood litter); those two types had the lowest production rates for all three sizes of bulldozers.

Of the three recent Federal publications, only the NWCG Fireline Handbook (National Wildfire Coordinating Group 1980) provided a single production rate for each fire behavior fuel model (for each size of bulldozer and slope class). Apparently that single rate was an effort to fulfill the fire managers' plea for "simple tables" for field use. The other two publications (Schmidt and Rinehart 1982; USDA Forest Service 1980) recognized that each fire behavior fuel model was actually represented by a variety of vegetational types. Again, the vegetational varieties might be grouped from the standpoint of fire behavior but not necessarily according to their resistance to line construction by bulldozers. For example, it seems apparent that there may be significant differences in the rates for different vegetational types within fuel model 6 when you compare "southern hardwood shrub with pine slash residues" to "pinyon-juniper with sagebrush and grass intermixed." The former vegetational type presents a rather continuous fuel bed of resistive vegetation; in the latter vegetational type, a bulldozer can usually maneuver easily among scattered pinyon pine and juniper trees and construct fireline through the sparse sagebrush and grass at a comparatively fast rate of speed. And apparently there is a considerable difference to be expected in bulldozer production rates in fuel model 9 between hardwood litter in the Western States and in the Southern States; depending on bulldozer size and slope class, the Federal tables show rates are lower in the Southern States by 67 percent to 233 percent. The question is whether or not those differences are real.

So, if simplicity of tables of bulldozer production rates in fireline handbooks is to be achieved through combining fire behavior fuel models, great care must be given in how the task is accomplished.

Simplifying tables of production rates by rounding off rates to the nearest 5 or 10 chains/hour was easier to do. The suggestion came from fire managers who pointed out the large variance in bulldozer production rates. If a fire manager, using a table of bulldozer production rates, calculates that a particular fireline can be constructed in 4 hours, the actual time may turn out to be anywhere from 2 to 8 hours. The variation can occur because of operator skill, age and condition of the equipment, amount of rock outcrops encountered, condition and age of the vegetation, variations in vegetational type, number and density of large trees that have to be moved, air temperature, and so forth. Many of these variables can be evaluated, and appropriate adjustments can be made in the tabulated production rates and in the expected completion time. But then there are possibilities that do not enter into the equation, such as equipment breakdown or a rock outcrop that may stall a bulldozer's progress for hours. Basing their thinking on the many known variables, fire managers suggested that rates like "7" or "21" or "68" appeared to be precise, which they were not. Therefore, why not use "5," "20," and "70"? The latter set of numbers, they suggested, would be easier to use on actual fires. Perhaps they are right.

Finally, the fire managers suggested that there should be only a single table of production rates. They pointed out that the differences in rates shown in table 1 (for bulldozers manufactured since 1975) and table 2 (for bulldozers manufactured between 1965 and 1975) were not great. The differences in rates were certainly well within the variation caused by other factors such as operators' skills, vegetative types, soil types, etc. A single table, they suggested, could present a range of rates for each set of the four primary variables with rules about how to use the rates in relation to assumed and real conditions.

Considering the many variables affecting the effectiveness of bulldozers in the construction of firelines, it was somewhat difficult to provide what the fire managers sought: a simplified table of production rates.

REVISED TABLE OF BULLDOZER FIRELINE PRODUCTION RATES

Taking into account the observations made during the verification study, the characteristics of tables found in recent Federal publications, and comments by experienced fire managers, the authors recalculated bulldozer fireline production rates and prepared new curves (figs. 2-4). Table 7 was then constructed by reading from the curves the range of rates and the midpoint rate for each set of variables. The rates were rounded off to the nearest 5 chains/hour except for those rates below 10 chains/hour. At the bottom of the table are rules for using the range of rates. Those rules specify when to use higher rates within each range, when to use lower rates, and when to use the midpoints.

Table 7 shows the limitations of operating bulldozers in slope class 4. Fire managers wishing to plan for bulldozer operations in the lower range of slope class 4 may need to derive rates from the curves in figures 1-3. Generally, bulldozers will not be able to construct fireline at the upper range of slope class 4, either upslope or downslope, except under the most favorable conditions of soil (somewhat moist and no obstructing rocks) and air temperature (between 65 and 85 °F).

Table 7 does not differentiate among various vegetational types that may occur within a single fire behavior fuel model. That omission, done for the sake of simplicity in the table, can be a serious shortcoming. Users of the tables should use lower rates for the more resistive vegetative types within a fuel model and higher rates for less resistive types, as stated in the rules for using the table.

Admittedly, the curves and table are subjective compromises of all available data and information. Considering the many variables that affect the rates, however, they are reasonably accurate for use in fire management planning.

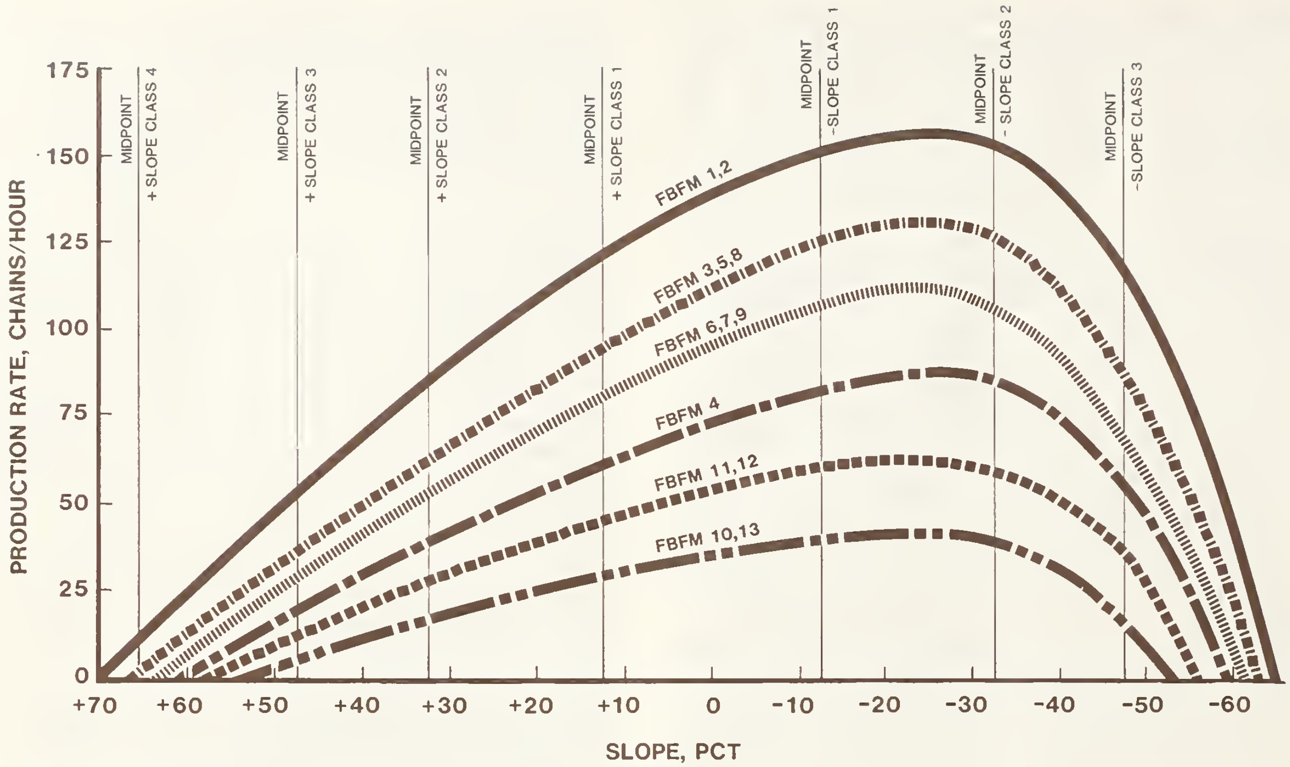

Figure 2—Production rates for large bulldozer, single pass.

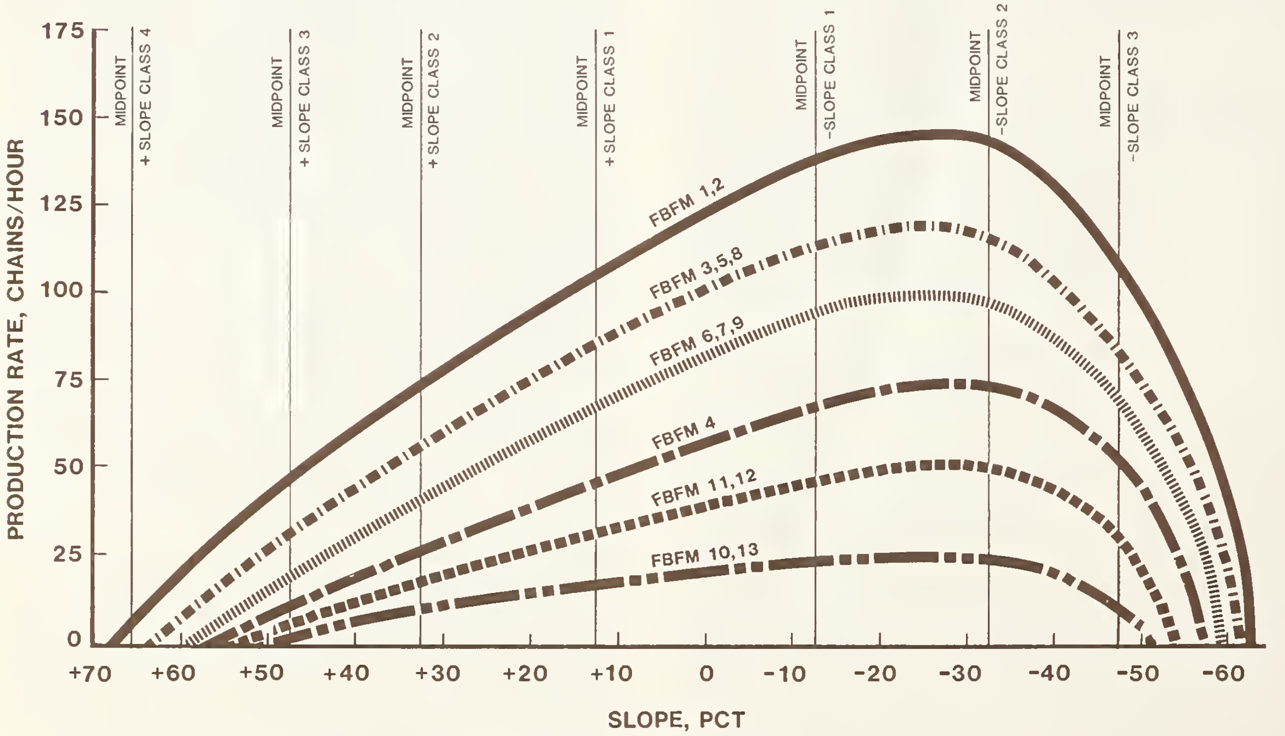

Figure 3—Production rates for medium bolldozer, single pass.

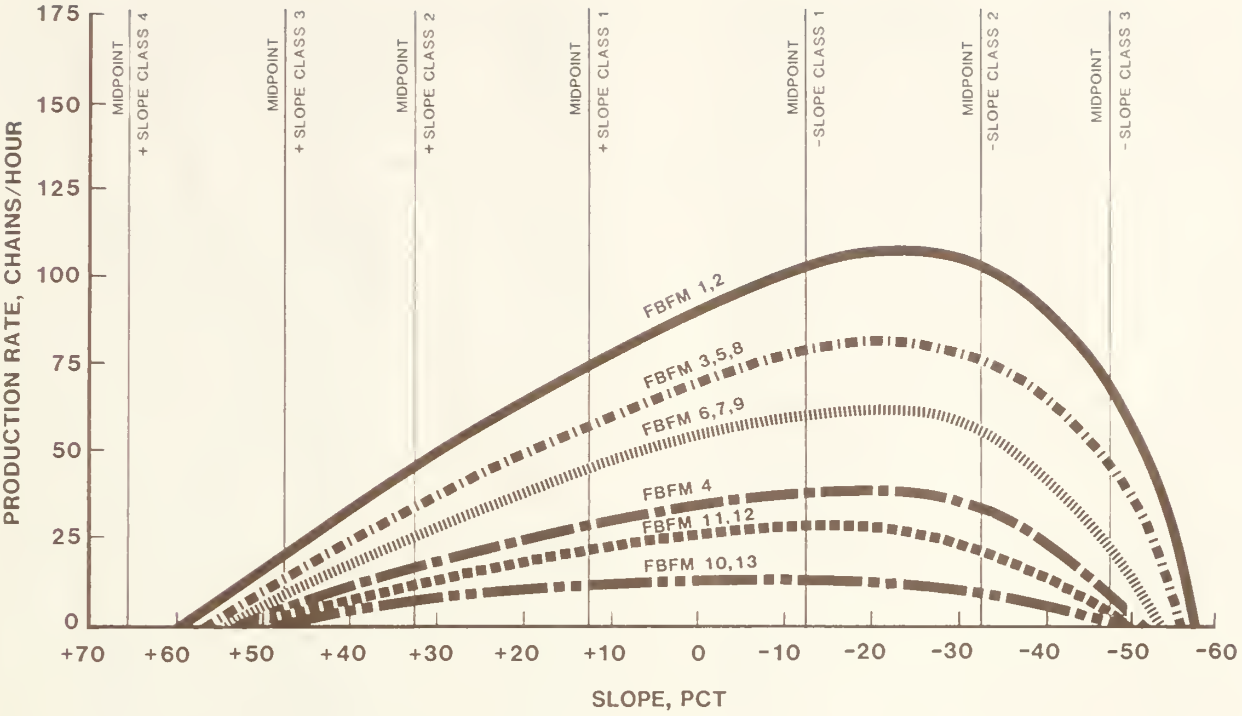

Figure 4—Production rates for small bulldozer, single pass.

Table 7—Bulldozer fireline production rates (single pass) in chains per hour; shown as a range of rates for each slope class, followed by the midpoint rate in parentheses

Fire behavior fuel model	Upslope or downslope	Slope class 1 (0-25%)	Slope class 2 (26-40%)	Slope class 3 (41-55%)	Slope class 4 (56-74%)
		Chains per hour			
Small bulldozers					
1, 2	Up	55-90(75)	30-55(45)	8-30(20)	0-8(0)
	Down	90-110(105)	90-110(105)	20-90(70)	0-20(0)
3, 5, 8	Up	45-70(60)	25-45(35)	2-25(10)	0-2(0)
	Down	70-80(80)	65-80(75)	0-65(45)	0
4	Up	20-35(30)	10-20(15)	0-10(4)	0
	Down	35-40(40)	25-40(35)	0-25(8)	0
6, 7, 9	Up	35-55(45)	15-35(25)	0-15(8)	0
	Down	55-60(60)	40-60(55)	0-40(20)	0
11, 12	Up	15-25(20)	7-15(10)	0-7(2)	0
	Down	25-30(30)	10-30(20)	0-10(3)	0
10, 13	Up	8-15(10)	3-8(6)	0-3(1)	0
	Down	10-15(15)	5-10(9)	0-5(2)	0
Medium bulldozers					
1, 2	Up	85-125(110)	60-85(75)	30-60(45)	0-30(6)
	Down	125-145(140)	130-145(145)	75-130(110)	0-75(0)
3, 5, 8	Up	70-105(85)	45-70(55)	15-45(30)	0-15(0)
	Down	105-120(115)	105-120(115)	55-105(85)	0-55(0)
4	Up	35-60(45)	20-35(25)	2-20(10)	0-2(0)
	Down	60-75(70)	65-76(75)	20-65(50)	0-20(0)
6, 7, 9	Up	50-85(70)	30-50(40)	7-30(20)	0-7(0)
	Down	85-100(95)	85-100(100)	40-85(70)	0-40(0)
11, 12	Up	25-40(30)	15-25(20)	1-15(7)	0-1(0)
	Down	40-55(45)	45-55(55)	0-45(35)	0
10, 13	Up	10-20(15)	7-10(8)	0-7(3)	0
	Down	20-25(25)	20-25(25)	0-20(10)	0
Large bulldozers					
1, 2	Up	100-140(120)	70-100(85)	35-70(55)	0-35(10)
	Down	140-155(150)	140-155(155)	85-140(115)	0-85(0)
3, 5, 8	Up	75-110(95)	50-75(60)	20-50(35)	0-20(1)
	Down	110-130(125)	110-130(125)	55-110(85)	0-55(0)
4	Up	45-70(60)	30-45(35)	8-30(20)	0-8(0)
	Down	70-85(80)	75-85(80)	25-75(55)	0-25(0)
6, 7, 9	Up	65-95(80)	40-65(50)	15-40(25)	0-15(0)
	Down	95-110(105)	90-110(105)	50-90(70)	0-50(0)
11, 12	Up	35-55(45)	20-35(25)	3-20(10)	0-3(0)
	Down	55-65(60)	55-65(60)	6-55(40)	0-6(0)
10, 13	Up	20-35(30)	9-20(15)	0-9(4)	0
	Down	35-40(40)	30-40(40)	0-30(15)	0

Rule for using the table: Production rates are not precise but will vary with conditions. The midpoint rates (parentheses) should be used for special studies, such as the USDA Forest Service's fire economics analysis. The higher rate for each set should be used for the following conditions: newer bulldozers (1975 or later model), bulldozers in excellent operating condition, most qualified operators, ambient air temperature of less than 90 °F, moist soil, few or no rocks, no lost time, indirect fireline, average fire behavior, daylight operations, and less resistive vegetative types within each fire behavior fuel model. The lower rate for each set should be used for: older bulldozers (1975 and older), bulldozers in poorer operating condition, poorly qualified operators, air temperature of 90 °F or more, very dry soil, very rocky soil, anticipated lost time, direct fireline, high-intensity fire behavior, night operations, and more resistive vegetative types within each fire behavior fuel model. For combinations of these conditions, use rates somewhere within the range given for each set.

Users of the rates should be mindful of the rule of use at the bottom of table 7 and of the discussion in this publication. The rule reflects what was observed during the verification study, especially in relation to two critical factors: soil and equipment operators. Moist soil which provides good traction may increase midpoint rates by 100 percent or more. In the opposite sense, the presence of large boulders or rock outcrops may decrease the midpoint rates by 60 to 70 percent. Even harmless-appearing flat slate can be a frustrating obstacle to experienced operators; bulldozer blades continuously hang up on flat slate that lies at a slight upward angle opposed to the direction of a bulldozer's travel. Inexperienced operators, observed at least twice during the verification study, produced slow production rates because they either wasted much motion by fighting adverse terrain or vegetation, or they were overly cautious and slow. Other conditions that might cause construction rates to fall into the lowest range of the table, or even lower, are as follows: night operations, poorly maintained equipment, ambient air temperature over 100 °F, a very resistive vegetational type within a given fuel model, time lost to mechanical breakdown or abandoned firelines, or other causes. On the other hand, a superior operator, ambient air temperature in the range of 65 to 85 °F, vegetation that less severely restricts a bulldozer's progress than represented by the fuel model in the table—all these things and others will likely produce rates at or above the highest rate of each range.

To sum up, the bulldozer fireline production rates in table 7 are guides, as the rule states. Those who use the table should understand how the rates were derived and adjust them according to conditions actually encountered on a specific fire.

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Presents current (1988) fireline production rates for bulldozers, by size of machine, fuel type, slope, and site conditions. Includes nomograms and a master table for estimating production rates. Describes how data were collected and production rates were calculated.

KEYWORDS: fire management, fire control, prescribed burning, fire technology

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